

## EAST

L Number	Hits	Search Text	DB	Time stamp
1	2	"20020192590"	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 11:57
2	594	((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 11:59
3	322	(((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:01
4	153	((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:03
5	49	((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 16:31
6	35	(((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (thermoplastic or coagulation or melt or melting)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:05
7	31	(((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (foam foaming foamed ablate ablation ablated)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:14
8	5	(((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (foam foaming foamed)	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:14

11	26	((((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (foam foaming foamed ablate ablation ablated)) not (((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (foam foaming foamed))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:23
12	14	((((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (thermoplastic or coagulation or melt or melting)) not (((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))) and (foam foaming foamed ablate ablation ablated))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:27

14	14	((((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) and (thermoplastic or coagulation or melt or melting)) not (((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) and (foam foaming foamed ablate ablation ablated)) not (((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) and (thermoplastic or coagulation or melt or melting)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:27
13	14	((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) not (((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) and (thermoplastic or coagulation or melt or melting)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:27
16	166	((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:31
17	47	((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) not (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:31

15	119	(((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:32
18	70	(((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) not ((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 12:32
20	1	mase-hiroshi\$.in. and (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:49
23	1	hirose-sumio\$.in. and (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:49
24	1	suzuki-yuko\$.in. and (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:49
25	1	matsumoto-katsuru\$.in. and (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:46
26	1	sanada-takayuki\$.in. and (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:49
27	3	mase-hiroshi\$.in. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:51
30	4	sanada-takayuki\$.in. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:50
29	4	hirose-sumio\$.in. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:51

28	4	suzuki-yuko\$.in. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:51
31	o	mitsui-chemicals\$.asn. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:52
32	o	mitsui-chemicals\$.asn. and (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:53
34	o	mitsui\$.asn. and ((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:53
33	6	mitsui\$.asn. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 14:53
35	3	(mitsui\$.asn. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate))) not (suzuki-yuko\$.in. and (((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 16:12
36	2	6030750.pn.	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 16:13
37	58	((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (processless waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 16:31
38	9	((((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (processless waterless or switchable or ("no" or "not") near5 (developing developer developers processing))) not (((((cross adj (link or linked)) or crosslink or crosslinked) same hydrophilic) and (printing adj plate)) and (cyanine or phthalocyanine or (carbon adj black) or polymethine or photothermal or phthalocyanine or benzoquinone or naphthoquinone)) and ((acrylamide vinylformamide formamide vinyacetamide acetamide methacrylamide) same hydrophilic)) and (waterless or switchable or ("no" or "not") near5 (developing developer developers processing)))	USPAT; US-PGPUB; EPO; JPO; DERWENT	2003/06/11 16:35

## Poly(methyl methacrylate), General

### **Synonym:**

Poly(methyl 2-methyl-2-propenoate)  
Poly[1-(methoxycarbonyl)-1-methyl ethylene]  
Acrylic  
PMMA

### **Monomers:**

Methyl methacrylate

### **Related Polymers:**

Polymethacrylates-General  
Moulding and Extrusion Compounds  
Cast Sheet (rods and tubes)  
Extruded Sheet  
Butyl methacrylate copolymer

### **Material Class**

Thermoplastic

### **Polymer Type:**

acrylic

### **CAS Reg. No.:**

9011-14-7 [general]; 25188-98-1 [isotactic]; 25188-97-0 [syndiotactic]

### **Molecular Formula:**

$(C_5H_8O_2)_n$

### **Fragment:**

$C_5H_8O_2$

### **Mol. Weight:**

MN 300000-6000000 (cast material); 100000-200000 (moulded or extruded material); 252000 (GPC determined); MW 481000 (GPC determined); MZ 766000 (GPC determined); MZ +1 1196000 (GPC determined)

### **Additives:**

PMMA materials may contain residual monomer or processing additives. Typical additives used in the manufacture of PMMA by suspension polymerisation (usually for moulding and extrusion compounds) include suspending agents, buffering agents, chain transfer agents (to control MW), lubricants and emulsifier. A number of additives may be blended with PMMA, perhaps the most important being dyes and pigments. Listings of commonly used colorants for PMMA have been reported. [1]

Sucrose-based additives improve heat stability. Plasticisers are sometimes used with PMMA, e.g. in moulding compositions to enhance the melt flow. Levels vary from 1-50%; 5% is typical.

Lubricants reduce heat dissipation during machining or polishing.

Some commercial grades contain uv absorbers (290-350 nm). This both screens the user from sunburn, e.g. in glazing applications, and protects the polymer against long term degradation from light. Typical levels are in the range 0.001-2%.

Alumina hydrate is used as a flame-retardant filler in some forms of PMMA used for bathroom fittings, kitchen worktops and 'synthetic marble'.

Fillers and reinforcements are not often used although chalk is sometimes incorporated, e.g. for opaque illuminated panels in advertising displays. PMMA can be reinforced, e.g. with glass fibre, polyethylene, Kevlar or carbon to ensure high mechanical strength at temps. around 100°.

Polystyrene (0.2-5%) may be added as an opalescent.

Rubber particles increase toughness

### **Tacticity:**

Although nominally atactic, conventionally produced PMMA is more syndiotactic than atactic.

Differences in the adsorption behaviour of atactic and tactic polymers have been reported: isotactic PMMA is absorbed onto silica (from acetonitrile soln.) whereas atactic PMMA is not. [4]

Stereoregular polymers may be prod. in soln. by use of anionic catalysts, e.g. organolithium compounds or Grignard reagents. Isotactic polymers tend to be prod. in non-polar solvents and syndiotactic in polar solvents. The change in composition of the product polymer in a series of reactions carried out in various toluene/dimethoxyethane mixtures using *n*-butyl lithium as initiator at -30° has been reported. [5]

Stereoregular PMMA can be made by living polymerisation in toluene using *tert*-butyl MgBr (for isotactic) or *tert*-butyl lithium aluminium alkyl (for syndiotactic). Living polymerisation also allows the preparation of star and comb-like polymers with stereoregular main and side chains, e.g. isotactic main chain and syndiotactic side chain [13,14]

#### Morphology:

Commercial grades are normally amorph.

Isotactic: orthorhombic a 41.96Å, b 24.34Å, c 10.50Å,  $\alpha$  92.9°,  $\beta$  88.2°,  $\gamma$  90.6° containing eight double-strand 10/1 helices per cell. [6,7,8] Repeat unit volume 87-89 cm<sup>3</sup> mol<sup>-1</sup> [9]; 89.3 cm<sup>3</sup> mol<sup>-1</sup>. [10]

The head-to-head polymer has been reported [11]

#### Identification:

Contains only C, H and O. The surface of any acrylic plastic is immediately fogged or crazed by Me<sub>2</sub>CO

#### General Info:

PMMA may be fractionated by means of supercritical fluid chromatography. [3] Commercially the most important member of the acrylate/methacrylate group of polymers, PMMA was first introduced in 1936 and is available as cast and extruded sheet, tubes, rods, powders, pellets, solns, dispersions and emulsions. In addition to its use in sheet form, PMMA is also suitable for many extrusion and moulding applications, coating and surface treatments and has many industrial uses.

It is non-toxic, odourless and tasteless. Nothing is extracted from PMMA by oil or water.

PMMA may be coloured to give transparent, translucent or opaque forms. It is possible to texture the surface of PMMA products during moulding or by later embossing and products may be further decorated by spray-painting, vacuum-metallising, hot stamping etc.

It is a clear, colourless, hard, brittle, fairly rigid material which can be drilled, carved or sawn and has exceptional optical clarity and resistance to degradation by uv light. The hardest and most heat resistant PMMA materials are the cast sheet products, followed by continuous cast materials, then the extruded or moulded products.

Its total internal reflection permits a wide light beam to be transmitted through long lengths of PMMA and around corners with little loss provided that the radius of curvature of the sheet or rod is three times its thickness.

Has good electrical insulating props. at low frequencies. Above its glass transition temp. PMMA is tough, pliable, extensible and easily bent or formed into complex shapes; at high temps., however, it is very susceptible to depolymerisation.

It is a polar material and will absorb some moisture but is resistant to alkali, detergent, oils and dilute acids.

Although PMMA has comparatively limited impact resistance this can be improved by copolymerisation, e.g. Butyl acrylate/MMA (see [Acrylic/methacrylic copolymers](#)) or acrylonitrile/MMA (see [Acrylonitrile-methyl acrylate copolymer](#)), or by blending e.g. with Poly(*n*-butyl acrylate) (see [Poly\(\*n\*-butyl methacrylate\)](#)) or a butadiene copolymer.

PMMA has low flammability, a high melt viscosity, low resistance to creep at temps. only a little above room temp., poor solvent resistance and a comparative lack of abrasion resistance.

## Volumetric and Calorimetric Properties

#### Density:

No.	Value	Note
1	1.15 – 1.23 <sup>25</sup> g/cm <sup>3</sup>	[2,6,18,19,22,23]
2	1.17 <sup>25</sup> g/cm <sup>3</sup>	amorph. [2,21]
3	1.19 <sup>23</sup> g/cm <sup>3</sup>	cast and extruded grades, 50% relative humidity, ISO 1183 [20]
4	1.19 <sup>30</sup> g/cm <sup>3</sup>	syndiotactic [18]
5	1.19 <sup>30</sup> g/cm <sup>3</sup>	conventional [18,19,20]
6	1.21 – 1.22 <sup>30</sup> g/cm <sup>3</sup>	isotactic [6,18]
7	1.23 <sup>25</sup> g/cm <sup>3</sup>	cryst. [2]

#### Thermal Expansion Coefficient:

No.	Value	Note
1	0.000048 – 0.00008 K <sup>-1</sup> [L]	impact modified, ASTM D696 [24]
2	0.00005 – 0.00006 K <sup>-1</sup> [L]	general purpose, cast sheet, ASTM D696 [24]
3	0.00007 K <sup>-1</sup> [L]	cast and extruded grades, 0-50°, DIN 53752-A [20]
4	0.000225 – 0.000295 K <sup>-1</sup> [V]	T < T <sub>g</sub> , 1 atm, free radical polymerisation [26]
5	0.00053 – 0.000575 K <sup>-1</sup> [V]	T > T <sub>g</sub> , 1 atm, free radical polymerisation

**Volumetric Properties General:**

Molar volumes at 25° [2]: 56.1 cm<sup>3</sup> mol<sup>-1</sup> van der Waals, 86.5 cm<sup>3</sup> mol<sup>-1</sup> glassy, 81.8 cm<sup>3</sup> mol<sup>-1</sup> cryst.

**Equation of State:**

Tait, Bruce-Hartmann, Sanchez and Lacombe, Spencer-Gilmore and Smka-Somcynsky equation of state information has been reported [27,28,29,30,31,32,33]

**Thermodynamic Props General:**

Thermal conductivity varies with both temp. and pressure although at ordinary pressure the variation is quite small. Control over thermomechanical props. can be improved by the addition of low MW poly(butyl methacrylate) or poly(butyl-co-methyl methacrylate). [35].

Molar heat capacity data for amorph. PMMA has been reported [42]

**Latent Heat of Cryst:**

Enthalpy of melting 9.6 kJ mol<sup>-1</sup>. [2] Entropy data for a range of temps. and pressures have been reported. [28] Entropy, enthalpy and Gibbs free energy data for temps. -263 -- 13° have been reported in a graphical form [36]

**Thermal Conductivity:**

No.	Value	Note
1	0.15 – 0.2 W/m K	[2]
2	0.15 – 0.161 W/m K	-50° [37]
3	0.17 W/m K	clear cast sheet, NBN B62-202 [41]
4	0.19 W/m K	cast and extruded grades, DIN 4701 [20]
5	0.197 W/m K	0.00047 cal (s cm °C) <sup>-1</sup> , 35° [38,39]
6	0.25 W/m K	100° [40]

**Specific Heat Capacity:**

No.	Value	Note
1	1.38 kJ/(kg °C) [P]	solid, 25° [2]
2	1.47 kJ/(kg °C) [P]	cast and extruded grades [20]
3	1.8 kJ/(kg °C) [P]	liq. 25° [2]

**Melting Temperature:**

No.	Value	Note
1	72°C	emulsion polymerisation, refractometric method [43]
2	160°C	isotactic [18]
3	>200°C	min., syndiotactic [18]

**Glass Transition Temperature:**

No.	Value	Note
1	41.5°C	isotactic 95%, atactic 5% [46]
2	43 – 45°C	isotactic [18,44,45]
3	54.3°C	isotactic 73%, atactic 16%, syndiotactic 11% [45]
4	61.6°C	isotactic 62%, atactic 20%, syndiotactic 18% [45]
5	80 – 100°C	impact-modified, ASTM D3418 [24]
6	85 – 105°C	ASTM D3418 [24]
7	90 – 105°C	cast sheet, ASTM D3418 [24]
8	104°C	isotactic 6%, atactic 30%, syndiotactic 56% [46]
9	105°C	conventional [26]
10	114.2°C	isotactic 10%, atactic 31%, syndiotactic 59% [45]
11	115°C	syndiotactic [18]
12	119.5°C	isotactic 10%, atactic 20%, syndiotactic 70% [46]
13	125.6°C	isotactic 9%, atactic 36%, syndiotactic 64% [45]
14	160°C	syndiotactic [44]

**Deflection Temperatures:**

No.	Value	Note
1	71 – 102°C	1.82 MPa, cast sheet, ASTM D648 [54]
2	74 – 99°C	1.82 MPa, impact-modified, ASTM D648 [54]
3	74 – 113°C	0.455 MPa, cast sheet ASTM D648 [54]
4	74 – 105°C	1.82 MPa, ASTM D648 [24]
5	76 – 106°C	1.82 MPa, MEC, ASTM D648, DIN 53461, ISO R-75 [22,23,46]
6	79 – 107°C	0.455 MPa, ASTM D648 [24]
7	82 – 102°C	0.455 MPa, impact-modified, ASTM D648 [54]
8	85 – 95°C	1.82 MPa, moulding compound, ASTM D648 [46]
9	88 – 102°C	ISO 75A [23]
10	90°C	1.8 MPa, extruded, ISO 75 [20]
11	91 – 106°C	ISO 75B [23]
12	95°C	0.45 MPa, extruded, ISO 75 [20]
13	100°C	1.82 MPa, sheet, ASTM D648 [46]
14	102°C	cast, ISO 75A [41]
15	105 – 107°C	1.8 MPa, cast, ISO 75 [20]
16	108°C	1.82 MPa, 75% glass fibre, pultrusion [47]
17	110°C	1.82 MPa, 75% glass fibre, pultrusion, post formed [47]
18	113°C	carbon fibre, pultruded [48]
19	113 – 115°C	0.45 MPa, cast, ISO 75 [20]
20	116°C	carbon fibre, pultruded and postformed [48]
21	117°C	Kevlar fibre, pultruded [48]
22	118°C	1.82 MPa, 58% carbon fibre, pultrusion [47]
23	119°C	Kevlar fibre, pultruded and postformed [48]

**Vicat Softening Point:**

No.	Value	Note
1	80 – 118°C	MEC, ASTM D1525, DIN 53460, ISO R-306 [22,23,46]
2	82 – 110°C	ASTM D1525 [24]
3	85 – 110°C	impact-modified, ASTM D1525 [24]
4	95 – 110°C	cast sheet, ASTM D1525 [24]
5	102°C	extruded, ISO 306-B50 [20]
6	109 – 112°C	moulding compound [46]
7	>110°C	min., cast sheet, ISO 306A [25]
8	115°C	cast, ISO 306-B50 [20]
9	119°C	[19]

**Transition Temperatures:**

N	Value	Note
1	8 – 26°C	$T_\beta$ [50]
2	12°C	isotactic [50]
3	24°C	atactic $T_\beta$ [50]
4	27°C	syndiotactic [50]
5	27°C	$T_\beta$ [2]
6	38°C	isotactic, crystalline [50]
7	56°C	MEC, ASTM grade 5, DIN grade 525 [51]
8	64°C	MEC, ASTM grade 6, DIN grade 526 [51]
9	72°C	MEC, DIN grade 527 [51]
10	80°C	MEC, ASTM grade 8, DIN grade 528 [51]
11	85°C	extruded, DIN 53458 [20]
12	95°C	cast, DIN 53458 [20]

**Brittleness Temperature:**

No.	Value	Note
1	80°C	Charpy-type impact, velocity $244 \text{ cm s}^{-1}$ , 3 mm thick [49]
2	90°C	emulsion polymerisation; refractometric method [43]

**Surface Properties and Solubility****Solubility Properties General:**

The solubility of PMMA can vary with tacticity, e.g. highly syndiotactic polymer is insol. in  $\text{C}_6\text{H}_6$  whereas the atactic material dissolves [52].

In some solvents, e.g. 2-butanone, butyl acetate, 2-ethoxyethanol, syndiotactic PMMA will only dissolve molecularly above 70°. Below this temp. aggregation occurs and, eventually, precipitation. Isotactic PMMA also precipitates but at lower temps. which vary significantly with solvent. Atactic PMMA does not precipitate from soln. even when cooled to -70° [52].

When solns. of syndiotactic and isotactic PMMA are mixed gelation results, probably as a result of stereocomplex formation. the solvents used exert a major influence on the formation of the stereocomplexes and the resultant effects on viscosity and associated props. [52].

Crystalline syndiotactic PMMA forms complexes with chloroacetone and other solvents. The solvent is necessary to maintain crystallinity [53]

**Cohesive Energy Density/Solubility Parameters:**

29.90-59.40  $\text{kJ mol}^{-1}$  [2]; 29.058-31.471  $\text{kJ mol}^{-1}$  (25-35°) [54];  $347 \text{ J cm}^{-3}$  [55];  $346-374 \text{ J cm}^{-3}$  (25-35°) [54].

Solubility parameter,  $\delta$   $18.2-26 (\text{J/cm}^3)^{0.5}$  (poor H-bonding solvents),  $17.4-27.2 (\text{J/cm}^3)^{0.5}$  (moderate H-bonding solvents), 0 (strong H-bonding solvents), [56]  $38.7 (\text{J/cm}^3)^{0.5}$ , [57]  $23.1 (\text{J/cm}^3)^{0.5}$ , [2]  $18.6-26.3 (\text{J/cm}^3)^{0.5}$ , 18.0-23.1 ( $\text{J/cm}^3)^{0.5}$  [9],  $\delta_d$  15.6-18.6 [9], 18.8 [2].  $\delta_p$  1.4-10.6 [9], 10.2, [2]  $\delta_h$  1-7.8, [9] 8.6. [2]

**Internal Pressure/Heat of Soln/Misc.:**

$\pi$  266 MPa (42.9°, MN 15000), 400 MPa (114.1°, MN 15000) [58]

**Plasticisers:**

Dimethyl phthalate, diethyl phthalate, dibutyl phthalate, benzyl butyl phthalate, dibutyl sebacate, diethylhexyl sebacate, phosphates are used as plasticisers. Antiplasticisation can occur. [59,60] The presence of plasticisers affects uptake of water [83]

**Surface/Interfacial Props General:**

The surface props. of PMMA can be altered by modification of the surface using graft copolymerisation [62] or by the incorporation of a surfactant into the polymer matrix. [63] PMMA forms an extremely viscoelastic condensed monolayer. At a surface conc. of  $0.00005 \text{ mg cm}^{-2}$  PMMA enters a biphasic state when small patches of condensed material develop [64]. Monolayer and surface viscosity parameters have been reported. [64] The nature of spread films at an air-water interface determined by neutron reflectometry has been reported [155,156,157]

**Solvents/Nonsolvents:**

Sol.  $\text{C}_6\text{H}_6$  (atactic) [52], xylene,  $\text{CH}_2\text{Cl}_2$ ,  $\text{CHCl}_3$ , chlorobenzene, isobutanol (hot), cyclohexanol (hot), ethoxyethanol, dioxane, 2-butanone, cyclohexanone,  $\text{AcOH}$ , isobutyric acid,  $\text{EtOAc}$ , cyclohexyl acetate,  $\text{EtOH}$  aq,  $\text{EtOH/CCl}_4$ , isopropanol/2-butanone (1:1,  $>25^\circ$ ), formic acid, nitroethane,  $\text{Me}_2\text{CO}$ , isopropyl methyl ketone, o-dichlorobenzene, cyclopentanone, pyridine, o-toluidene.

Insol. hexane, cyclohexane, gasoline, Nujol, castor oil,  $\text{MeOH}$ , ethylene glycol, glycerol, formamide, turpentine, linseed oil, hydrogenated naphthalenes,  $\text{CCl}_4$ ,  $\text{EtOH}$ , butylene glycol,  $\text{Et}_2\text{O}$ , higher esters, m-cresol, Freon-215, isopentane, isoctane, n-pentane, n-octane, methyl cyclohexane, n-propanol, n-amyl alcohol,  $\text{C}_6\text{H}_6$  (highly syndiotactic) [52,61,62]

**Wettability/Surface Energy/Interfacial Tension:**

Contact angle,  $\phi$   $80^\circ$  ( $\text{H}_2\text{O}$ , advancing,  $20^\circ$ ) [65,66];  $58^\circ$  ( $\text{H}_2\text{O}$ , advancing) [84];  $41^\circ$  (methylene iodide,  $20^\circ$ ) [65];  $59^\circ$  (air, 3%  $\text{H}_2\text{O}$  present) [69];  $89^\circ$  ( $\text{Me}_2\text{CO}$ , 3%  $\text{H}_2\text{O}$  present) [69].

Surface energy Parachlor 224 [67], MacLeod's 4.2 (MV 3000) [68]. Polarity 0.281 (MV 3000) [68].  $-\frac{d\gamma}{dT}$  0.076  $\text{mN m}^{-1} \text{ K}^{-1}$  (MV 3000) [68].

Critical surface tension  $40 \text{ mN m}^{-1}$  [65],  $39 \text{ mN m}^{-1}$  [66].

Interfacial tension  $11.9 \text{ mN m}^{-1}$  (polyethylene, linear,  $20^\circ$ ) [68],  $3.2 \text{ mN m}^{-1}$  (polystyrene,  $20^\circ$ ) [68],  $3.4 \text{ mN m}^{-1}$  (poly n-butyl methacrylate,  $20^\circ$ ) [68],  $3.0 \text{ mN m}^{-1}$  (poly tert-butyl methacrylate,  $20^\circ$ ) [71],  $23.6\text{-}24.1 \text{ mN m}^{-1}$  ( $\text{H}_2\text{O}$ , 3%  $\text{H}_2\text{O}$  present) [69]

**Surface Tension:**

No.	Value	Note
1	$27 - 44 \text{ mN/m}$	[2]
2	$60.1 - 61.8 \text{ mN/m}$	3% $\text{H}_2\text{O}$ present [69]
3	$62 \text{ mN/m}$	after contact with $\text{H}_2\text{O}$ [70]

**Transport Properties****Melt Flow Index:**

No.	Value	Note
1	$0.5 - 24 \text{ g/10 min}$	$230^\circ$ , 3.8 kg, MEC, ASTM D1238, DIN 53735, ISO 1133 [22,23,72]

**Polymer Solutions Dilute:**

Intrinsic viscosity [73].  $\eta_{inh}$   $850 \text{ dl g}^{-1}$  ( $25^\circ$ ,  $\text{C}_6\text{H}_6$ ),  $190 \text{ dl g}^{-1}$  ( $25^\circ$ ,  $\text{CHCl}_3$ ),  $560 \text{ dl g}^{-1}$  ( $25^\circ$ , DMF),  $530 \text{ dl g}^{-1}$  ( $25^\circ$ ,  $\text{EtOAc}$ ),  $90\text{-}4140 \text{ dl g}^{-1}$  ( $25^\circ$ , toluene). Viscosity is not greatly affected by tacticity but varies with MW [74]. Theta temps.  $-126^\circ$  ( $\text{Me}_2\text{CO}$ ),  $-223^\circ$  ( $\text{C}_6\text{H}_6$ ),  $27^\circ$  ( $\text{CCl}_4$ ),  $-273^\circ$  ( $\text{CHCl}_3$ ),  $-98^\circ$  ( $\text{EtOAc}$ ),  $5\text{-}85^\circ$  (propanol),  $-65^\circ$  (toluene) [58,75]

**Polymer Melts:**

The melt viscosity of MEC compounds is usually higher than that of most other polymers. Newtonian viscosity  $50 \text{ kN s m}^{-2}$  ( $200^\circ$ ). PMMA has a small consistency index and so the viscosity is very sensitive to temp. changes. Control over the viscosity of PMMA can be improved by the addition of low MW poly(butyl methacrylate) or

poly(butyl-co-methyl methacrylate) [35]. Because of its small power law index [76] PMMA is very sensitive to shear rate [77]

#### **Permeability f Gases:**

Permeability [20]  $[H_2O] 2.3 \cdot 10^{-10} \text{ g cm cm}^{-2} \text{ h}^{-1} \text{ Pa}^{-1}$  (cast and extruded grades);  $[O_2] 2.0 \cdot 10^{-14}$  (cast and extruded grades);  $[N_2] 4.5 \cdot 10^{-15}$  (cast and extruded grades);  $[CO_2] 1.1 \cdot 10^{-13}$  (cast and extruded grades); [air]  $8.3 \cdot 10^{-15}$  (cast and extruded grades).

Permeability coefficient, P [78,79];  $[O_2] 0.032-0.105 \cdot 10^{-10} \text{ cm}^3 \text{ cm}^{-2} \text{ s}^{-1} (\text{cmHg})^{-1}$ ,  $35^\circ$ , 1-2 atm;  $[He] 3.75-9.57 \cdot 10^{-10}$ ;  $[H_2] 1.29-4.70 \cdot 10^{-10}$ ;  $[N_2] 0.0014-0.0130 \cdot 10^{-10}$ ;  $[Ar] 0.0047-0.0308 \cdot 10^{-10}$ ;  $[CH_4] 0.00098-0.0064 \cdot 10^{-10}$ ;  $[CO_2] 0.050-0.415 \cdot 10^{-10}$

#### **Perm ability of Liquids:**

Diffusion coefficients  $[Me_2CO] 2.2-6.8 \cdot 10^{-7} \text{ cm}^2 \text{ s}^{-1}$  ( $20^\circ$ , MW 201000-6350000);  $[n\text{-butyl chloride}] 14.9-22.4 \cdot 10^{-7}$  ( $34.5^\circ$ , MW 29000-16000),  $1.15-7.18 \cdot 10^{-7}$  ( $35.6^\circ$ , 6550000-200000);  $[EtOAc] 2.34-7.21 \cdot 10^{-7}$  ( $20^\circ$ , 931000-79000);  $[methyl methacrylate] 1.51-1.95 \cdot 10^{-7}$  (MW 454000-370000);  $[toluene] 5.8 \cdot 10^{-7}$  ( $20^\circ$ , MW 115000);  $[H_2O] 51 \cdot 10^{-7}$  ( $37^\circ$ ),  $1.3 \cdot 10^{-7}$  ( $50^\circ$ ) [84,85];  $[H_2O] 5.2 \text{ g cm cm}^{-2} \text{ h}^{-1} (\text{mmHg})^{-1}$  ( $25^\circ$ ) [82]

#### **Permeability and Diffusion General:**

Isotactic PMMA is less permeable to gases than is the syndiotactic form [78]

#### **Water Content:**

Water absorption decreases with increasing amount of plasticiser. 0.3-0.36% (MEC, ASTM D570, DIN 53495, ISO R-62) [22,23]

#### **Wat r Absorption:**

No.	Value	Note
1	<2.3%	max. [84]
2	0.1 – 0.4%	24h, ASTM D570 [24]
3	0.2 – 0.6%	24h, impact modified, ASTM D570 [24]
4	0.2 – 0.4%	24h, cast sheet, ASTM D570 [24]
5	0.2 – 0.4%	ISO 62 [25]

## **Mechanical Properties**

#### **Mechanical Properties General:**

The deformation of PMMA is temp. dependent. Increasing temp. leads to greater elongation but reduced strength. The temp. dependence of the viscoelastic props. is due to the temp. dependence of the  $\alpha$  and  $\beta$  relaxation times which are in turn controlled by the rate of molecular movement of the side group ( $\beta$  process) and the backbone ( $\alpha$  process). The temp. at which these movements start corresponds to a change in failure mode from brittle to ductile. The storage modulus is affected by the presence of plasticiser [87].

The tensile strength of PMMA can be increased when the polymer is drawn into fibres. A sixfold increase compared to the bulk resin has been found at high draw ratios, with the Young's modulus of the polymer increasing tenfold [88]. Fibre reinforcement can greatly improve the tensile strength at elevated temps.

#### **Tensile Modulus:**

N.	Value	Note
1	318 MPa	in air, 23° [90]
2	1300 MPa	75°
3	2241 – 3240 MPa	ASTM D638 [24]
4	2413 – 3103 MPa	cast, ASTM D638 [24]
5	2415 – 3100 MPa	impact modified, ASTM D638 [24]
6	2700 MPa	H <sub>2</sub> O, 37°, MW 1600000 [90]
7	2900 MPa	cast, 5 mm thick [91]
8	3180 MPa	23°, MW 1600000 [90]
9	3200 MPa	[20,21,89,92]
10	3300 MPa	cast and extruded grades, short term, ISO 527 [20]
11	3800 MPa	[93]
12	12000 MPa	35% glass fibre

**Flexural Modulus:**

No.	Value	Note
1	2241 – 3240 MPa	ASTM D790 [24]
2	2758 – 3448 MPa	cast sheet, ASTM D790 [24]
3	2760 – 3450 MPa	impact modified, ASTM D790 [24]
4	2900 – 3400 MPa	MEC, ASTM D790, DIN 53452, ISO R-178 [22,23]
5	2960 – 3210 MPa	cast, ISO 178 [25]
6	3000 MPa	[2]

**Complex Moduli:**

Compressive modulus  $25.51\text{--}32.75 \cdot 10^{-8}$  MPa (3.70–4.75 •  $10^{-5}$  psi, ASTM D695)[97]

**Tensile Strength at Break:**

No.	Value	Note
1	0 MPa	100° [86]
2	35 MPa [4.5%]	70°, extruded, ISO 527 [20]
3	38 – 85 MPa [4-40%]	MEC, ASTM D638, DIN 53455, ISO 527 [22,23]
4	38.8 MPa	75° [86]
5	40 MPa [5.5%]	70°, cast, ISO 527 [20]
6	48 – 76 MPa	ASTM D638 [24]
7	55 – 76 MPa [2-40%]	impact modified, ASTM D638 [24]
8	55 – 76 MPa	cast sheet, ASTM D638 [24]
9	62 – 75 MPa [4%]	ISO 527/1 [25]
10	65 MPa [10%]	[2]
11	65.5 MPa	50° [86]
12	72 MPa [4.5%]	23°, extruded, ISO 527 [20]
13	80 MPa [5%]	[1]
14	80 MPa [5.5%]	23°, cast, ISO 527 [20]
15	83.3 MPa	25° [86]
16	100 MPa [4.5%]	-40°, extruded, ISO 527 [20]
17	110 MPa [5.5%]	-40°, cast, ISO 527 [20]
18	112 MPa	100°, 10% glass fibre [86]
19	120 MPa	35% glass fibre [1]
20	153 MPa	25°, 10% glass fibre [86]
21	848 MPa	75% glass fibre, pultruded [47]
22	1035 MPa	75% glass fibre, pultrusion/postformed [47]
23	1345 MPa	Kevlar fibre, pultruded [48]
24	1435 MPa	carbon fibre, pultruded [48]
25	1503 MPa	58% carbon fibre, pultruded [47]
26	1621 MPa	Kevlar fibre, pultruded, postformed [48]
27	1662 MPa	carbon fibre, pultruded, postformed [48]

#### Flexural Strength at Break:

No.	Value	Note
1	105 MPa	extruded, ISO 178 [20]
2	105 – 116 MPa	ISO 178 [25]
3	110 MPa	[2]
4	112 MPa	cast, ASTM D695 [51]
5	115 MPa	cast, ISO 178 [20]
6	120 MPa	moulding powder, ASTM D695 [51]
7	129 MPa	2 mm min <sup>-1</sup> , ISO 178 [41]
8	248 MPa	Kevlar fibre, pultruded [48]
9	345 MPa	Kevlar fibre, pultruded, postformed [48]
10	366 MPa	carbon fibre, pultruded [48]
11	434 MPa	58% carbon fibre, pultruded [47]
12	524 MPa	carbon fibre, pultruded, postformed [48]
13	579 MPa	75% glass fibre, pultruded [47]
14	862 MPa	75% glass fibre, pultrusion, postformed [47]

#### Impact Strength:

Instrumented falling weight impact strength 0.3-0.6 J (MEC, ISO R-6603/2) [23]. There is some loss of impact strength at low temps. but it remains high enough for use at -40°

#### Viscoelastic Behavior:

Creep compliance data for the atactic form have been reported [100]. Compressibility at a given pressure increases with increasing temp. [105]. Other viscoelastic props. have been reported [154]

**Elastic Moduli:**

No.	Value	Note
1	0 MPa	100°, [86]
2	1300 MPa	75° [86]
3	3100 MPa	50° [86]
4	3300 MPa	25° [86]
5	2400 – 9130 MPa	Plexiglas, no applied pressure [94]

**Mechanical Properties Miscellaneous:**

Williams-Landel-Ferry constants for temp. superposition [100,101,102], Vogel parameters [101], entanglement MW [2,98,103] and relative entanglement moduli [104] have been reported. Failure strength (alternating bending test) 1000000 cycles [20], 40 MPa (cast, unnotched), 30 MPa (extruded, unnotched) 20 MPa (cast, notched), 10 MPa (extruded, notched)

**Poisson's Ratio:**

No.	Value	Note
1	0.32	[93]
2	0.327	Plexiglas, no applied pressure [94]
3	0.34	cast, -25-50° [91]
4	0.36	[95]
5	0.4	[24]
6	0.45	cast and extruded grades [20]

**Tensile Strength at Yield:**

No.	Value	Note
1	41.4 – 62 MPa [2-7%]	6-9 kpsi, cast, type I [96]
2	55.2 – 68.9 MPa [2-7%]	8-10 kpsi, cast, type II [96]

**Flexural Strength at Yield:**

No.	Value	Note
1	82.7 – 96.5 MPa	12-14 kpsi, cast, type I [96]
2	82.73 – 131 MPa	12-19 kpsi, ASTM D790 [97]
3	103.4 – 117.2 MPa	15-17 kpsi, cast, type II [96]

**Compressive Strength:**

No.	Value	Note
1	41 – 124 MPa	MEC, ASTM D695, DIN 53454, ISO R-604 [22,97]
2	75 – 131 MPa	11-19 kpsi, ASTM D695 [97]
3	82.7 – 96.5 MPa	12-14 kpsi, 2% offset, cast, type I [96]
4	96.5 – 124.1 MPa	14-18 kpsi, 2% offset, cast, type II [96]
5	103 MPa	extruded, ISO 604 [20]
6	110 MPa	cast, ISO 604 [20]

**Misc. Moduli:**

No.	Value	Note
1	1000 – 1500 MPa [shear modulus]	$1.0\text{--}1.5 \cdot 10^9 \text{ N m}^{-2}$ [28]
2	1700 MPa [shear modulus]	cast and extruded grades, 10 Hz, ISO 527 [20]
3	5100 MPa [bulk modulus]	0.51 dynes $\text{cm}^{-2}$ [92]
4	5930 MPa [bulk modulus]	Plexiglas, no pressure [94]
5	6000 MPa [bulk modulus]	approx. 6 GN $\text{m}^{-2}$ [98]

**Hardness:**

Rockwell M38-M102 [2,106,107], R125 [2]. Ball indentation hardness 172 MPa ( $17.2 \cdot 10^7 \text{ N m}^{-2}$ ) [2]; 200 MPa (ISO

2039-1) [108]; 175 MPa (cast and extruded grades, ISO 2039-1) [20]. Moh hardness 2-3 [106,107]; Brinell hardness 20 [106,107]. Vickers hardness 5 [106], 17.1 (0.500" thick), 17.9 (0.125" thick), 19.0 (0.060" thick) [107]. Knoop hardness 16 [106], 17.7 (MW 45000), 18.6 (MW 64000), 20.4 (MW 123000), 21.3 (MW 393000), 21.8 (MW 1615000) [107]. Barcol hardness 80 [106], 87 (sheet), 85 (MEC grade 8), 80 (MEC grade 6), 77 (MEC grade 5), 56 (high impact) [107]. Shore 90 [106], 85 [2], 90 (sheet), 90 (MEC grade 8), 88 (MEC grade 6), 87 (MEC grade 5), 77 (high impact) [107]. Schleroscope 99 [106,107]. Sward rocker 46 [107]. Kohinoor pencil 9H [107]. Bierbaum scratch 16.4 [107]

#### **Failure Properties General:**

Craze resistance 30-3600 s (min.) to break (MEC, ICI cantilever test, isopropanol) [23]. When the temp. is below the brittle-ductile transition point, PMMA fails by brittle fracture. Above this temp. it undergoes general yielding [109].

The presence of sorbed water at levels below 1% reduces the fatigue resistance of both cast and extruded PMMA. At levels above 1% there is little further loss of resistance. [109]

For both high and low MW PMMA the strain to fracture increases to a max. and then drops to low values as the water content rises [109]. In low MW PMMA craze-dominated fracture occurs at all water content levels whereas in high MW resins this is only true for water-saturated material. [109]

PMMA mouldings usually show considerable molecular orientation and it has been noted that a moulding with a high degree of 'frozen-in' orientation is stronger and tougher in the direction parallel to the orientation than in the transverse direction. When stress is applied parallel to the orientation direction the resistance to crazing is high; when stress is applied at 90° to this direction resistance to crazing is low. Large numbers of short, thin crazes are prod. in the former case and a comparatively small number of long, thick crazes in the latter [110]

#### **Fracture Mechanical Properties:**

Fracture surface energy per unit area,  $\gamma$ ,  $300 \text{ J m}^{-2}$  ( $3 \cdot 10^5 \text{ erg cm}^{-2}$ , MN 3000000) [111],  $200\text{-}400 \text{ J m}^{-2}$  [112],  $120 \text{ J m}^{-2}$  ( $1.2 \cdot 10^5 \text{ erg cm}^{-2}$ ) [113].

Fracture surface energy increases with decreasing temp. and varies with MW.

The value of  $\gamma$  is lowered significantly by cross-linking.  $80 \text{ J m}^{-2}$  (lightly cross-linked, 80000 erg cm $^{-2}$ ) [113];  $46 \text{ J m}^{-2}$  (cross-linked-PMMA/EGDMA, 46500 erg cm $^{-2}$ ) [114];  $23 \text{ J m}^{-2}$  (densely cross-linked, 23000 erg cm $^{-2}$ ) [113]. Critical stress intensity factor (fracture toughness),  $K_c$   $1.1 \text{ MN m}^{-3/2}$ ,  $1.21 \text{ MPa m}^{1/2}$  (MW 1600000, 23°) [90],  $0.7\text{-}1.6 \text{ MN m}^{-3/2}$  [98];  $1.76 \text{ MPa m}^{1/2}$  (in water, 37°, MW 1600000),  $1.21 \text{ MPa m}^{1/2}$ , (air value) [90]. Because of the dependence of its  $K_c$  value on crack velocity PMMA is prone to time-dependent failure during periods of prolonged loading

#### **Friction Abrasion and Resistance:**

Coefficients of friction 0.4-0.8 (self), 0.5 (steel) [1,20,115], 0.45 (steel) [1,20]. Abrasion resistance 0.025 N (Martens method, cast and extruded grades) [20]. Data for falling abrasive methods have been reported [107]

#### **Izod:**

N	Value	Note
1	15 – 64 J/m [Yes]	MEC, ASTM D256, ISO R180-4a [22]
2	16 – 26.7 J/m [Yes]	0.3-0.5 lbf in $^{-1}$ , standard [99]
3	16.2 – 32.4 J/m [Yes]	general purpose, cast sheet, ASTM D256 [24]
4	21.4 J/m [Yes]	0.4 ft lb in $^{-1}$ , cast, types I and II [96]
5	35 – 135 J/m [Yes]	impact modified, ASTM D256 [24]
6	53.4 – 122.8 J/m [Yes]	1.0-2.3 lbf in $^{-1}$ , high impact [99]
7	1200 J/m [Yes]	58% carbon fibre, pultruded [47]
8	1400 J/m [Yes]	carbon fibre, pultruded [48]
9	1700 J/m [Yes]	carbon fibre, pultruded, postformed [48]
10	2000 J/m [Yes]	75% glass fibre, pultruded [47]
11	2200 J/m [Yes]	75% glass fibre, pultruded, postformed [47]
12	2400 J/m [Yes]	Kevlar fibre, pultruded [48]
13	2800 J/m [Yes]	Kevlar fibre, pultruded, postformed [48]

#### **Izod Area:**

No.	Value	Note
1	16 kJ/m <sup>2</sup> [No]	cast and extruded grades, ISO 180/1A [20]
2	18 kJ/m <sup>2</sup> [No]	DIN 53453 [28]
3	1200 – 2170 kJ/m <sup>2</sup> [Yes]	cast sheet, ISO 179/2D
4	1200 kJ/m <sup>2</sup> [No]	cast sheet, ISO 179/2D
5	2000 kJ/m <sup>2</sup> [Yes]	DIN 53453 [28]

**Charpy:**

No.	Value	Note
1	2 – 7 kJ/m <sup>2</sup> [Yes]	MEC, DIN 53453, ISO R179-2C [22]
2	5.9 kJ/m <sup>2</sup> [Yes]	0.11 ft lb in <sup>-1</sup> [99]
3	11 – 19 kJ/m <sup>2</sup> [No]	cast, ISO R179 [41]
4	11 – 60 kJ/m <sup>2</sup> [No]	MEC, DIN 53453, ISO R179-2D [22]
5	15 kJ/m <sup>2</sup> [No]	cast and extruded grades, ISO 179/1fu [20]

**Electrical Properties****Electrical Properties General:**

PMMA has a low electrical conductivity, good arc resistance and high dielectric strength. The electrical props. are hardly affected by the absorption of water or the presence of plasticiser. PMMA is about midway in the triboelectric series for polymers [115]. The dielectric constant and dissipation factor of PMMA vary with both temp. and frequency. The effects of ion-implantation on the props. of PMMA can be quite extensive [116].

**Surface Resistivity:**

No.	Value	Note
1	0.05 10 <sup>15</sup> ohm	cast and extruded grades, DIN VDE 0303, part 3 [20]
2	0.1 10 <sup>15</sup> ohm	cast sheet, IEC 93 [25]
3	0.1 10 <sup>15</sup> ohm	MEC, ASTM D257, DIN 53482 [22]
4	1 10 <sup>15</sup> ohm	DIN 53482 [1]
5	600 10 <sup>15</sup> ohm	cast, ASTM D257 [51]

**Volum Resistivity:**

No.	Value	Note
1	>0.1 10 <sup>15</sup> ohm cm	min., rises with polarisation time, ASTM D257 [97,117]
2	>0.1 10 <sup>15</sup> ohm cm	min., rises with polarisation time [20,22,97,117]
3	>1 10 <sup>15</sup> ohm cm	min., MEC, ASTM D257, DIN 53482 [22]
4	>1 10 <sup>15</sup> ohm cm	min., cast and extruded grades, DIN VDE 0303, part 3 [20]

**Arc Resistance:**

No.	Value	Note
1	s	no track, ASTM D495

**Magnetic Properties:**

Magnetic susceptibility, c 0.59 • 10<sup>6</sup> cm<sup>3</sup> g<sup>-1</sup> [122]. The effect of ion-implantation on the props. of PMMA can be quite extensive [116].

**Strong Field Phenomena General:**

The dielectric strength of PMMA is high at low temps. but falls rapidly at the critical temp., T<sub>c</sub> (approx. 20°) [121].

**Static Electrification:**

The high surface resistance can give rise to a surface static charge but this can be prevented by the application of an anti-static surface coating [51].

**Dielectric Strength:**

No.	Value	Note
1	15 – 20 kV/mm	ASTM D149, DIN 53581, IEC 243 [22,25]
2	15 – 20 kV/mm	impact modified, ASTM D149 [24]
3	16 – 20 kV/mm	ASTM D149 [24]
4	18 – 22 kV/mm	cast sheet, ASTM D149 [24]
5	30 kV/mm	cast and extruded grades, 1 mm thick, DIN VDE 0303, part 2 [20]

**Dielectric/Permittivity Constant:**

No.	Value	Note
1	2.2 – 3.7	ASTM D150 [2]
2	2.57 [30 GHz]	25° [119,120]
3	2.59 [138 GHz]	25° [120]
4	2.6 [1 MHz]	25@ [118]
5	2.7 [100 kHz]	23°, cast, DIN VDE 0303, part 4 [20]
6	2.8 [100 kHz]	23°, extruded, DIN VDE 0303, part 4 [20]
7	3 [1 kHz]	25° [118]
8	3.6 [50 Hz]	25° [118]
9	3.6 [50 Hz]	23°, cast, DIN VDE 0303, part 4 [20]
10	3.7 [50 Hz]	23°, extruded, DIN VDE 0303, part 4 [20]
11	3.7 – 3.9 [50 Hz]	MEC, ASTM D150, DIN 53483 [22]

**Dissipation Factor:**

No.	Value	Note
1	0.0056 [30 GHz]	25° [119,120]
2	0.01 [138 GHz]	25° [120]
3	0.014 [1 MHz]	25° [118]
4	0.02 [100 kHz]	23°, cast, DIN VDE 0303, part 4 [20]
5	0.03 [100 kHz]	23°, extruded, DIN VDE 0303, part 4 [20]
6	0.04 [1 MHz]	MEC, ASTM D150, DIN 53483 [22]
7	0.055 [1 kHz]	25° [118]
8	0.06 [50 Hz]	23°, cast and extruded grades, DIN VDE 0303, part 4 [20]
9	0.062 [50 Hz]	25° [118]

**Optical Properties****Optical Properties General:**

Temp. coefficient of refractive index -0.001°. Extinction modulus 55000 mm<sup>-1</sup> (647 nm) [124]; 50000 mm<sup>-1</sup> (633 nm) [117]; 19000 mm<sup>-1</sup> (514 nm) [124]; 23000 mm<sup>-1</sup> (488 nm) [124]; 10000 mm<sup>-1</sup> (400 nm) [117]. PMMA exhibits the Kerr effect with a Kerr constant of  $0.2 \cdot 10^{-14}$  mV<sup>2</sup> (25°, commercial cast grade) [125]. Stress optical coefficient  $-160 \cdot 10^{12}$  Pa<sup>-1</sup> [126]. Large heterogeneities in PMMA give rise to light-scattering loss. Light-scattering loss 13 dB km<sup>-1</sup> (633 nm; polymer with no heterogeneities prep'd. by radical polymerisation above T<sub>g</sub>) [127,128]

**Refractive Index:**

No.	Value	Note
1	1.4831	633 nm, syndiotactic [130]
2	1.4832	633 nm, isotactic [130]
3	1.488	656 nm, n <sub>c</sub> [129]
4	1.49	589 nm [2,20,22,23,129]
5	1.496	486 nm, n <sub>f</sub> [129]

**Transmission and Spectra:**

Nmr [12,13,14], Raman [15], ir [16], esr [123] and time-of-flight negative ion mass [17] spectral data have been reported.

PMMA transmits light in the range 360-1000 nm; at a thickness of 2.54 cm or less it absorbs virtually no visible light; above 2800 nm essentially all ir radiation is absorbed.  $\lambda_{\max}$  213 nm (syndiotactic, extinction coefficient 170-173 M<sup>-1</sup> cm<sup>-1</sup>, 16.5-65°) [131];  $\lambda_{\max}$  207 nm, with shoulders at 211.5 and 216.5 nm (isotactic, 17.5°) [131].

Deuteration of the monomer prior to polymerisation can extend the transmission window and improve the loss of a resin, the degree of improvement depending on the level of deuteration [132]. Deuterated PMMA has a lower optical absorption coefficient than PMMA in both the visible and the near infrared regions [133]. Water in PMMA causes some loss of transmission around 950 nm but otherwise has little effect on the absorption props. Water in deuterated PMMA, however, has a much greater effect [133].

The transparency of PMMA to X-rays is similar to that of human flesh or water. Finely-divided inorganic salts have been added to PMMA to render it opaque to X-rays but there is a detrimental effect on the mechanical props. Bismuth and barium-containing glasses have been similarly used but again the mechanical props. suffer with the polymer increasing in weight and becoming brittle. PMMA can be made radio-opaque by the incorporation of heavy metal salts during polymerisation. The presence of the salt can sometimes raise the  $T_g$  of the polymer [134]. Sheets are opaque to  $\alpha$ -particles and for thicknesses above 6.35 nm they are essentially opaque to  $\beta$ -radiation. PMMA sheet may be used as a neutron stopper. Most colorless sheet formulations have high transmittance to standard broadcast and TV waves and most radar bands. Total energy transmittance 85% (cast and extruded grades, DIN 67507) [20]

#### **Molar Refraction:**

Dispersion 57.8 [129]. The complex refractive index of syndiotactic and isotactic PMMA over the ir region has been calculated [130]

#### **Total Internal Reflect:**

Critical angle 42° (air, 5893Å) [46,51]. Intrinsic segmental anisotropy,  $2 \cdot 10^{25} \text{ cm}^3$  ( $\text{C}_6\text{H}_6$ , atactic),  $25 \cdot 10^{25} \text{ cm}^3$  ( $\text{C}_6\text{H}_6$ , isotactic) [135]

#### **Volume Properties/Surface Properties:**

Haze 20-30% (Taber method, ISO 9352, cast and extruded grades). Clarity 90-92% transmission (D1003, DIN 5036) [20,22,23]. Haze 0.4-2.5% (max., D1003, DIN 5036) [22,23]

#### **Stability**

##### **Polymer Stability General:**

Uv irradiation of thin films at 25° can cause a rapid decrease in MW with small amounts of volatile prods. formed [148]. The carbonyl group absorbs at 215 nm leading to chain scission and consequent degradation. Large doses of ionising radiation can cause brittleness, loss of strength and general reduction in props. Main chain fracture occurs during irradiation; deterioration of props. is due to lowering of MW. Non-heat resistant grades distorted by boiling  $\text{H}_2\text{O}$ . High energy radiation causes irreversible yellowing but no change in mechanical or electrical props.  $\gamma$ -Irradiation causes chain rupture [149] leading to decrease in  $T_g$  and intrinsic viscosity [150].

#### **Upper Use Temperature (Long Term):**

No.	Value	Note
1	65 – 90°C	[1]
2	70°C	extruded [20]
3	75 – 80°C	thermoformings [41]
4	80°C	continuous use, cast sheet [25]
5	80°C	cast [20]
6	80 – 85°C	flat sheet [41]
7	85 – 100°C	[1]

#### **Decomposition Details:**

On heating the polymer above 300° an unzipping process occurs giving monomer at >95% yield. The main prods. of combustion in a well-ventilated atm. are  $\text{CO}_2$  and CO [136,137,138,139,140].  $k_{350}$  5.2% min<sup>-1</sup> [46]. Heat of combustion 16600 kJ kg<sup>-1</sup> [140]. Char yield 0% [98]

#### **Flammability:**

Burns slowly with a blue, crackling flame and little smoke; liable to drip. Burns to completion if not extinguished. Flame-retardant grades are available. Limiting oxygen index 17.3% [2,141]. Flammability rating HB (UL 94) [25].

Ignition temp. 425° [1], 425° (cast, DIN 51794) [20], 430° (extruded, DIN 51794) [20], 350° (moulding powder) [51]

#### **Environmental Stress:**

Can last up to 20 years with little appreciable loss of props. After a period of 17 years' exposure in New Mexico a sample of sheet was found to have reduced flexural strength (-51%) and strain at rupture (-66%). The material had a slightly reduced glass transition temp. and was also more brittle, although the brittleness was attributed partly to crack initiation by surface roughness. The sheet was still transparent and the loss in transmission less than 10%. The original degree of transmission could be almost completely restored by polishing, showing that the loss was due to surface roughness rather than degradation of the polymer [142]. Is more stable to photolysis in air than in a vacuum [143]. Outdoor weathering causes very slight yellowing after 1095 days (general purpose/cast sheet, ASTM D1435) and embrittlement after 730 days (ASTM D1435) [24]. Rain drops may cause ring cracks [144]. Resistance to environmental stress cracking may be improved by annealing

#### **Biological Stability:**

PMMA with a small amount of *N*-benzyl-4-vinylpyridinium chloride in the main chain shows a reduction in MW after time in the aeration tank of a sewage works

#### **Chemical Stability:**

Resistant to oxidation at ambient temps. May be crazed by solvents and organic compounds [98]. Cast sheet may be rendered opaque by MeOH [145]. Unaffected by weak acids and alkalis. Attacked by strong acids [24]. Ozonolysis causes degradation [146]

#### **Hydrolytic Stability:**

There is a marked difference between crystallisable and non-crystallisable forms. Conventional (i.e., free-radical bulk polymerised) and syndiotactic polymers hydrolyse more slowly than isotactic [147]. The config. of the polymer is unchanged by hydrol.

#### **Recyclability:**

May be recycled via pyrolysis at 720° when depolymerisation yields monomer at 97% or better

#### **Stability Miscellaneous:**

Uv irradiation of thin films at 25° can cause a rapid decrease in MW with small amounts of volatile prods. formed [148]. The carbonyl group absorbs at 215 nm leading to chain scission and consequent degradation. Large doses of ionising radiation can cause brittleness, loss of strength and general reduction in props. Main chain fracture occurs during irradiation; deterioration of props. is due to lowering of MW. Non-heat resistant grades distorted by boiling.

H<sub>2</sub>O. High energy radiation causes irreversible yellowing but no change in mechanical or electrical props.  $\gamma$ -Irradiation causes chain rupture [149] leading to decrease in T<sub>g</sub> and intrinsic viscosity [150]

### **Applications/Commercial Products**

#### **Proc/Manuf Routes:**

Manufactured by bulk (sheet, rod or tube), suspension, soln. or dispersion [152] polymerisation. Free-radical polymerisation can be initiated by AIBN or a peroxide at 100°, by bacteria and yeast [151], or by heat or microwave-inducement [158]. Stereoregular material is made by living polymerisation using metal alkyl catalysts [153]. Processed by manipulation (sheet, rod, tube) or by extrusion and injection moulding

#### **Mold Shrinkage:**

No.	Value	Note
1	0.2 – 0.6%	ASTM D955 [25]
2	0.4 – 0.7%	[23]

#### **Applications:**

Applications in consumer goods; in medicine as dental cements/resins, hard contact lenses and in bone reconstruction. Also used in the manufacture of membranes for dialysis and ultrafiltration. Used as a positive photoresist both with uv (at 215 nm) and with an electron beam, although its sensitivity to the latter is low. Also used as a low-profile additive to eliminate polymerisation shrinkage in sheet moulding compounds and bulk moulding formulations e.g., in PVC

#### **Tradenames:**

Tradenames	Grade	Manufacturer/Supplier
------------	-------	-----------------------

Acrifix		Rohm and Haas
Acrigel DH/MP		Proquigel
Acry Sirop		Mitsubishi Chemical
Acrybase		Rohm and Haas
Acryex	CM 200 range	Chi Mei Industrial
Acrylite		CYRO Industries
Acryloid		Rohm and Haas
Acrylt	WD/WH/WM	Sumitomo Chem Co
Acrylub		Rohm and Haas
Acrypanel		Mitsubishi Chemical
Acryptet		Mitsubishi Chemical
Altuglas and Altucite		Altulor Groupe CdF, France
Aravite	CW 8730 / HW 8730 / CY 8740	Ciba-Geigy Corp.
Asterite		ICI Acrylics
Barex	200 range; extrusion and injection moulded	BP Chemicals
Biodrak		A. Drakopoulos, Greece
Casoglas and Casorcyl		Casolith BK, Netherlands
Conap	CE-1170	Conap Inc.
Cryolite	G-20-100/G-20-300	CYRO Industries
Degalan		Degussa
Degoplast		Degussa
Deglas		Degussa
Delpet and Delpet		Asahi Chem. Co Ltd
Dewoglas		Degussa
Diakon		ICI Acrylics
Elecroglass		Glasfix Corp., USA
Elvacite		ICI Acrylics
Eska		Mitsubishi Chemical
Exolite		CYRO Industries
Gardlite		Southern Plastics Co., USA
Kamax	T series	AtoHaas N.A.
Lacrilex		LATI Industria Thermoplastics S.p.A.
Lucite		ICI Acrylics
Lucky		Lucky Ltd.
Modar	various grades	ICI Acrylics Inc.
MS	100 series; 300/600	Network Polymers
NAS/P-605	various grades	Novacor Chemicals
Neocryl		Zeneca
NSC	A-101/A-126	Thermofil Inc.
Optix	PL range	Plaskolite Inc.
Oroglass		Rohm and Haas
Palapet		Kyowa Gas Chem., Japan
Paraglas		Degussa
Paraloid		Rohm and Haas
Perma Stat	1800	RTP Company
Perspex		ICI Acrylics
Piacryl		VEB Piesteritz, Germany
Plexidur		Rohm and Haas
Plexiglas		Rohm and Haas
PMMA	various grades	Lucky
Resartglas		Resart-Ihm, Germany
Resartit		Resart-Ihm, Germany

RX9-901		Spartech
Shinkolilthe		Mitsubishi Chemical
Sumipex		Sumitoma Chemical, Japan
Swedcast		Swedlow Inc., USA
Umaplex		Synthesia, Czechoslovakia
Unilock		British Vita Co., UK
Vedril		Vedril SpA, Italy
Vestiform		Huls AG
Vetredil		Vetril, Italy
Zylar	ST range/93 series	Novacor Chemicals

## References

- [1] Domininghaus, H., Plastics for Engineers, Hanser, 1993, 276, (colourings).
- [2] Van Krevelen, D.W., Properties of Polymers: Their Correlation with Chemical Structure, Elsevier, 1976, 79, (MW).
- [3] De Boer, A., Van Ekenstein, G.O.R.A. and Challa, G., Polymer, 1975, 16, 930, (chromatography).
- [4] Hamori, E., Forsman, W.E. and Hughes, R.E., Macromolecules, 1971, 4, 193,.
- [5] Cowie, J.M.G., Polymers: Chemistry and Physics of Modern Materials, 2nd edn., Blackie, 1991, 406, (tacticity).
- [6] Boscher, F., Ten Brinke, G., Eshuis, A. and Challa, G., Macromolecules, 1982, 15, 1364, (morphology).
- [7] Kusanagi, Chatani, Y. and Takadono, H., Macromolecules, 1976, 9, 531, (morphology).
- [8] Hadjichristidis, N., Makromol. Chem., 1977, 178, 1463, (morphology).
- [9] Barton, A.F.M., CRC Handbook of Polymer-Liquid Interaction Parameters and Solubility Parameters, CRC Press, 1990, 265,.
- [10] Ahmed, H. and Yaseen, M., Polym. Eng. Sci., 1979, 19, 858,.
- [11] Vogel, O. and Grossman, S., Encycl. Polym. Sci. Eng., 2nd edn., (ed. J.I. Kroschwitz), Wiley Interscience, 1988, 7, 632,.
- [12] Konishi, T., Tamai, Y., Fuji, M., Einaga, Y. and Yamakawa, H., Polym. J. (Tokyo), 1989, 21, 329, (C-13 nmr, H-1 nmr).
- [13] Kitayama, T., Ute, K. and Hatada, K., Br. Polym. J., 1990, 23, 5, (synth., nmr).
- [14] Kitayama, T., Nakagawa, O. and Hatada, K., Polym. J. (Tokyo), 1995, 27, 1180, (synth.).
- [15] Neppel, A. and Butler, I.S., J. Raman Spectrosc., 1984, 15, 247, (Raman).
- [16] Miyamoto, T. and Inagaki, H., Polym. J. (Tokyo), 1970, 1, 46, (ir).
- [17] Lub, J., Van Vroonhoven, F.C.B.M., Van Leyen, D. and Benninghoven, A., J. Polym. Sci., Part B: Polym. Phys., 1989, 27, 2071, (ms).
- [18] Shetter, J.A., J. Polym. Sci., Part B: Polym. Lett., 1962, 1, 209, (density).
- [19] Hoff, E.A.W., Robinson, D.W. and Willbourn, A.H., Polym. Sci., 1955, 18, 161, (density).
- [20] Plexiglas Datasheet, Rohm and Haas, 1996, (technical datasheet).
- [21] Chee, K.K., J. Appl. Polym. Sci., 1987, 33, 1067, (density).
- [22] Oroglass Granules, ICI, 1996, (technical datasheet).
- [23] Diakon Range, ICI, 1996, (technical datasheet).
- [24] Harrington, M., Handbook of Plastic Materials and Technology, (ed. I.I. Rubin), Wiley Interscience, 1990, 355, (thermal expansion).
- [25] Perspex Cast Extruded Sheet, ICI, 1996, (technical datasheet).
- [26] Olabisi, O. and Simba, R., Macromolecules, 1975, 8, 206,.
- [27] Spencer, R.S. and Gilmore, G.D., J. Appl. Phys., 1950, 21, 523, (eqn. of state).
- [28] Progelhof, R.C. and Throne, J.L., Polymer Engineering Principles, Hanser, 1993, 254, (eqn. of state).
- [29] Simha, R., Wilson, P.S. and Olabisi, O., Kolloid Z. Z. Polym., 1973, 251, 402, (eqn. of state).
- [30] Beret, S. and Prausnitz, J.M., Macromolecules, 1975, 8, 206, (eqn. of state).
- [31] Quach, A., Wilson, P.S. and Simha, R., J. Macromol. Sci., Phys., 1974, 9, 533, (eqn. of state).
- [32] Olabasi, O. and Simha, R., Macromolecules, 1975, 8, 211, (eqn of state).
- [33] Hartmann, B., Simha, R. and Berger, A.E., J. Appl. Polym. Sci., 1991, 43, 983, (eqn. of state).
- [34] Sanchez, I.C. and Lacombe, R.H., J. Polym. Sci., Polym. Lett. Ed., 1977, 15, 71, (eqn. of state).
- [35] Emel'yanov, D.N. and Myachev, V.A., Plast. Massy, 1988, 5, 10, (thermodynamic props.).

- [36] Warfield, R.W. and Petree, M.C., *J. Polym. Sci., Part A: Polym. Chem.*, 1963, 1, 1701.,
- [37] Barber, R.E., Chen, R.Y.S. and Frost, R.S., *J. Polym. Sci., Polym. Phys. Ed.*, 1977, 15, 1199, (thermal conductivity).
- [38] Calvert, E., Bros, J.P. and Pinelle, H., *C.R. Hebd. Seances Acad. Sci.*, 1965, 260, 1164, (thermal conductivity).
- [39] Eiermann, K., *Kolloid Z. Z. Polym.*, 1964, 198, 5, (thermal conductivity).
- [40] Baschirow, A.B., Selenew, J.W. and Aschundow, S.K., *Plaste Kautsch.*, 1976, 23, 351, (thermal conductivity).
- [41] Perspex SW Cast Sheet, ICI, 1996, (technical datasheet).
- [42] Gaur, U., Lau, S.F., Wunderlich, B.B. and Wunderlich, B., *J. Phys. Chem. Ref. Data*, 1982, 11, 1065, (heat capacity).
- [43] Wiley, R.H. and Brauer, G.M., *J. Polym. Sci.*, 1948, 3, 647.,
- [44] Karey, F.E. and MacKnight, W.J., *Macromolecules*, 1968, 1, 537.,
- [45] Thompson, E.V., *J. Polym. Sci., Part A-2*, 1966, 4, 199.,
- [46] Brydson, J.A., *Plast. Mater.*, Butterworth, 1982, 371, 383.,
- [47] Chen-Chi, M.M.A. and Chin-Hsing, C., *Polym. Eng. Sci.*, 1991, 31, 1094, (mechanical and thermal props.).
- [48] Chen-Chi, M.M.A. and Chin-Hsing, C., *J. Appl. Polym. Sci.*, 1992, 44, 819, (mechanical props.).
- [49] Lal, J. and Trick, G.S., *J. Polym. Sci., Part A: Polym. Chem.*, 1964, 2, 4559.,
- [50] Plazek, D.J. and Ngai, K.L., *Physical Properties of Polymers Handbook*, (ed. J.E. Mark), AIP Press, 1996, 139.,
- [51] *Handbook of Industrial Materials*, Trade and Technical Press, 1978, 343.,
- [52] Belnikovitch, N.G., Mrkvickova, L. and Quadrat, O., *Polymer*, 1983, 24, 700, 713, 719, (solubility).
- [53] Kusuyama, H., Miyamoto, N., Chatani, Y. and Tadokoro, H., *Polym. Commun.*, 1983, 24, 119, 1256.,
- [54] Lee, W.A. and Sewell, J.H., *J. Appl. Polym. Sci.*, 1968, 12, 1397.,
- [55] Billmeyer, F.W., *Textbook of Polymer Science*, Wiley Interscience, 1962.,
- [56] Grulke, E.A., *Polym. Handb.*, 3rd edn., (eds. J. Brandrup and E.H. Immergut), Wiley Interscience, 1989, VII, 379, (solubility parameters).
- [57] Frank, C.W. and Gashgari, M.A., *Macromolecules*, 1979, 12, 163.,
- [58] Allen, G., Sims, D. and Wilson, G.J., *Polymer*, 1961, 2, 375.,
- [59] *Mod. Plast.*, 1958, 36, 135.,
- [60] *Soc. Plast. Eng., Tech. Pap.*, 1963, 19, 623.,
- [61] Fuchs, O., *Polym. Handb.*, 3rd edn., (eds. J. Brandrup and E.H. Immergut), Wiley Interscience, 1989, VII, 379.,
- [62] Ichijima, H., Okada, T., Uyama, Y. and Ikada, Y., *Makromol. Chem.*, 1991, 192, 1213.,
- [63] Torstensson, M., Randby, B. and Hult, A., *Macromolecules*, 1990, 23, 126.,
- [64] Kawaguchi, M., Sauer, B.B. and Yu, H., *Macromolecules*, 1989, 22, 1735.,
- [65] Zisman, W.A., *Adv. Chem. Ser.*, 1964, 43, 1.,
- [66] Owen, M.J., *Physical Properties of Polymers Handbook*, (ed. J.E. Mark), AIP Press, 1996, 669.,
- [67] Sewell, J.H., *J. Appl. Polym. Sci.*, 1973, 17, 1741.,
- [68] Wu, S., *J. Phys. Chem.*, 1970, 74, 632.,
- [69] King, R.N., Andrade, J.D., Ma, S.M., Gregonis, D.E. and Brostrom, L.R., *J. Colloid Interface Sci.*, 1985, 103, 62, (interfacial tension).
- [70] Ayme, J.C., Emery, J., Lavielle, G. and Schultz, J., *J. Mater. Sci.: Mater. Med.*, 1992, 1, 387.,
- [71] Wu, S., *J. Polym. Sci., Part C: Polym. Lett.*, 1971, 34, 19.,
- [72] Degalan Range, Degussa, 1997, (technical datasheet).
- [73] Stickler, M. and Sutterlin, N., *Polym. Handb.*, 3rd edn., (eds. J. Brandrup and E.H. Immergut), Wiley Interscience, 1989, VII, 183, (viscosity).
- [74] Sawatari, N., Konishi, T., Yoshizaki, T. and Yamakawa, H., *Macromolecules*, 1995, 28, 1089, 1095, (viscosity).
- [75] Elias, H.G., *Polym. Handb.*, 3rd edn., (eds. J. Brandrup and E.H. Immergut), Wiley Interscience, 1989, VII, 205, (theta temps.).
- [76] Tadmor, Z. and Gogos, C.G., *Principles of Polymer Processing*, Wiley, 1979.,
- [77] Thermoplastics, Wiley, 1974.,
- [78] Min, K.E. and Paul, D.R., *J. Polym. Sci., Polym. Phys. Ed.*, 1988, 26, 1021, (gas permeability).
- [79] Chiou, J.S. and Paul, D.R., *J. Appl. Polym. Sci.*, 1986, 32, 2897, (gas permeability).
- [80] Barker, R.E., *J. Polym. Sci.*, 1962, 58, 553.,

- [81] MacCullum, R.J. and Rudkin, A.L., *Eur. Polym. J.*, 1978, 14, 655, (diffusion coefficients).
- [82] Bueche, F., *J. Polym. Sci.*, 1954, 14, 414, (liq. permeability).
- [83] Kalachandra, S. and Turner, D.T., *J. Polym. Sci., Part B: Polym. Phys.*, 1987, 25, 697,.
- [84] Kalachandra, S. and Kusy, R.P., *Polymer*, 1991, 32, 2428, (liq. permeability).
- [85] Lechner, M.D. and Steineier, D.G., *Polym. Handb.*, 3rd edn., (eds. J. Brandrup and E.H. Immergut), Wiley Interscience, 1989, VII, 61, (liq. permeability).
- [86] Lin, H., Day, D.E. and Stoffer, J.O., *Polym. Eng. Sci.*, 1992, 32, 5, (mechanical props.).
- [87] Kalachandra, S., Kusy, R.P., Wilson, T.W., Shin, I.D. and Stejskal, E.O., *J. Mater. Sci.: Mater. Med.*, 1993, 4, 509,.
- [88] Buckley, C.A., Lautenschlager, E.P. and Gilbert, J.L., *J. Appl. Polym. Sci.*, 1992, 44, 1321,.
- [89] Froelich, D, PhD Thesis, University of Strasbourg, 1966,.
- [90] Johnson, J.A. and Jones, D.W., *J. Mater. Sci.*, 1994, 29, 870,.
- [91] Aly El-Sayed, A.-E.-E., Takeda, N. and Takahashi, K., *J. Phys. D: Appl. Phys.*, 1989, 22, 687,.
- [92] Warfield, R.W., Cueves, J.E. and Barnet, F.R., *J. Appl. Polym. Sci.*, 1968, 12, 1147,.
- [93] Kusy, R.P. and Turner, D.T., *Polymer*, 1974, 15, 394,.
- [94] Weischaupt, K., Krebeck, H. and Pietalle, M., *Polymer*, 1995, 36, 3267,.
- [95] Sandor, B.I., *Strength Mater. (Engl. Transl.)*, Prentice-Hall, 1978, 412,.
- [96] The Materials Selector, 2nd edn., (eds. N.A. Waterman and M.F. Ashby), Chapman and Hall, 1997,.
- [97] Guide to Plastics, Property and Specification Charts, (ed. W.A. Kaplan), McGraw-Hill,.
- [98] Mills, N.J., *Plastics Microstructure and Engineering Applications*, 2nd edn., Edward Arnold, 1993, 38,.
- [99] Encycl. Polym. Sci. Technol., (eds. N.F. Mark, N.G. Gaylord and N.M. Bikales), Wiley Interscience, 1971, 589, 607, (impact strength).
- [100] Ferry, J.D., *Viscoelastic Properties of Polymers*, 3rd edn., Wiley, 1980, 330,.
- [101] Masuda, T., Toda, N., Aota, Y. and Onogi, S., *Polym. J. (Tokyo)*, 1972, 3, 315, (viscoelastic props.).
- [102] Ngai, K.L. and Plazek, D.J., *Physical Properties of Polymers Handbook*, (ed. J.E. Mark), AIP Press, 1996, 341, (viscoelastic props.).
- [103] Wu, S. and Beckerbauer, *Polym. J. (Tokyo)*, 1992, 24, 1437, (viscoelastic props.).
- [104] Osaki, K., Takatori, E., Watenabe, H. and Kotaka, T., *Rheol. Acta*, 1993, 32, 132, (viscoelastic props.).
- [105] Shtarkmann, B.P., Monich, J.M. and Arzhakov, S.A., *Polym. Sci. USSR (Engl. Transl.)*, 1976, 18, 1206, (compressibility).
- [106] Crawford, R.J., *Plast. Eng. (N.Y.)*, Pergamon Press, 1981,.
- [107] Test. Polym., (ed. J.V. Schmitz), Wiley Interscience, 1965, 2,.
- [108] Oberbach, K., *Kunststoffe*, 1989, 79, 713,.
- [109] Chen, C.C., Shen, J. and Sauer, J.A., *Polymer*, 1985, 26, 89, 511,.
- [110] Beardmore, P. and Rabinowitz, S., *J. Mater. Sci.*, 1975, 10, 1763,.
- [111] Berry, J.P., *J. Polym. Sci.*, 1961, 50, 107,.
- [112] Young, R.J. and Lovell, P.A., *Introduction to Polymers*, 2nd edn., Chapman and Hall, 1991, 400,.
- [113] Broughton, L.J. and McGarry, F.J., *J. Appl. Polym. Sci.*, 1965, 9, 609,.
- [114] Berry, J.P., *J. Polym. Sci., Part A-1*, 1963, 1, 993,.
- [115] Van Krevelen, D.W. and Hoflyzer, P.J., *Properties of Polymers: Their Correlation with Chemical Structure*, 1972,.
- [116] Jenekhe, S.A., *Encycl. Polym. Sci. Eng.*, Wiley Interscience, 1988, 352,.
- [117] Schreyer, G., *Konstr. Kunstst.*, (ed. G. Schreyer), Hanser, 1972,.
- [118] Schreyer, G., *Kunststoffe*, 1965, 55, 771,.
- [119] Amrhein, G., *Kolloid Z. Z. Polym.*, 1967, 216-217, 38,.
- [120] Zeil, W., Sistig, R., Frank, W. and Hoffman, V., *Ber. Bunsen-Ges. Phys. Chem.*, 1970, 74, 883,.
- [121] Oakes, W.G., *Proc. Inst. Electr. Eng.*, 1949, 96, 37,.
- [122] Bedwell, M.E., *J. Chem. Soc.*, 1947, 1350,.
- [123] Tsay, F.-D. and Gupta, A., *J. Polym. Sci., Part B: Polym. Phys.*, 1987, 25, 855, (esr).
- [124] Crist, B., Marhic, M.E., Raviv, G. and Epstein, M., *J. Appl. Phys.*, 1980, 51, 1160, (extinction modulus).
- [125] Kim, K.S., Cheng, T.C. and Cooper, D.E., *J. Appl. Phys.*, 1983, 54, 449, (Kerr effect).

- [126] Dibbs, M.G., *Encycl. Polym. Sci. Eng.*, 1988, 16, 151.,
- [127] Tanio, N., Koike, Y. and Ohtsuka, Y., *Polym. J. (Tokyo)*, 1989, 21, 119, (light-scattering).
- [128] Koike, Y., Tanio, N. and Ohtsuka, Y., *Macromolecules*, 1989, 22, 1367, (light-scattering).
- [129] Almand, P. and Byrd, R., *Mater. Eng. (Cleveland)*, 1972, 76, 42, (refractive index).
- [130] Pacansky, J., England, C. and Waltman, R.J., *J. Polym. Sci., Part B: Polym. Phys.*, 1987, 25, 901, (refractive index).
- [131] D'Alagri, M., De Santis, P. Liquori, A.M. and Savino, M., *J. Polym. Sci., Polym. Lett. Ed.*, 1964, 2, 925, (uv).
- [132] Kaius, T., Jinguiji, K. and Nara, S., *Appl. Phys. Lett.*, 1982, 41, 802.,
- [133] Avakian, P., Hsu, W.Y., Meakin, P. and Snyder, H.L., *J. Polym. Sci., Polym. Phys. Ed.*, 1984, 22, 1607.,
- [134] Cabasso, I., Smid, J. and Sahni, S.K., *J. Appl. Polym. Sci.*, 1989, 38, 1653.,
- [135] Tsetkov, V.N. and Boitzkova, N., *Vysokomol. Soedin., Ser. A*, 1960, 3, 1176.,
- [136] Zemany, P.D., *Nature (London)*, 1953, 171, 391, (thermal degradation).
- [137] Straus, S. and Madorsky, S.L., *J. Res. Natl. Bur. Stand., Sect. A*, 1953, 50, 165, (pyrolysis).
- [138] Cowley, P.R.E.J. and Melville, H.W., *Proc. R. Soc. London*, 1952, A210, 461, (photodegradation).
- [139] Grassie, N., Scotney, A. and Makinson, L., *J. Polym. Sci., Polym. Chem. Ed.*, 1977, 15, 251, (photodegradation).
- [140] Tewarson, A., *Physical Properties of Polymers Handbook*, (ed. J.E. Mark), AIP Press, 1996, 577, (flammability).
- [141] Vaccari, J.A., *Mater. Eng. (Cleveland)*, 1977, 85, 31, (flammability).
- [142] Rainhart, L.G. and Schimmel, J., *Effect of Ageing on Acrylic Sheet*, Inter-Solar Energy, Soc. Paper, 1974.,
- [143] Dolezel, B., *Die Beständigkeit von Kunststoffen und Gummi*, Carl Hanser, 1978, 209.,
- [144] Ind. Photogr., 1960, 9, 23.,
- [145] Lin, C.B., Liu, K.S. and Lee, S., *J. Polym. Sci., Part B: Polym. Phys.*, 1991, 29, 1457, (stability).
- [146] Barnard, D., *J. Polym. Sci.*, 1956, 22, 213, (ozonolysis).
- [147] U.S. Pat., 1962, 3 029 228.,
- [148] Fox, R.B., Isaacs, L.G. and Stokes, S., *J. Polym. Sci., Part A: Polym. Chem.*, 1963, 1, 1079, (uv stability).
- [149] Schultz, A.R., *J. Polym. Sci.*, 1959, 35, 369, (irradiation).
- [150] Lin, C.B. and Lee, S., *J. Appl. Polym. Sci.*, 1992, 44, 2213, (irradiation).
- [151] Imoto, M., Ouchi, T., Inaba, M., Tokuyama, T. *et al*, *Polym. J. (Tokyo)*, 1981, 13, 105, (synth.).
- [152] Maury, E.E. and DeSimone, J.M., *Abstr. Pap.-Am. Chem. Soc., Poly* 490, (synth.).
- [153] Kityama, T., Ute, K. and Hatada, K., *Br. Polym. J.*, 1990, 23, 5, (synth.).
- [154] Aharoni, S.M., *Macromolecules*, 1983, 16, 1722, (viscoelastic props.).
- [155] Henderson, J.A., Richards, R.W., Penfold, J., Shackleton, C. and Thomas, R.K., *Polymer*, 1991, 32, 3284.,
- [156] Henderson, J.A., Richards, R.W., Penfold, J. and Thomas, R.K., *Macromolecules*, 1993, 26, 65.,
- [157] Henderson, J.A., Richards, R.W., Penfold, J. and Thomas, R.K., *Acta Polym.*, 1993, 44, 184.,
- [158] Albert, P. *et al*, *Acta Polym.*, 1996, 47, 74.,
- [159] Albert, P., *et al*, *Acta Polym.*, 1996, 47, 74.,
- [160] Henderson, J.A., *et al*, *Polymer*, 1991, 32, 3284.,
- [161] Henderson, J.A., *et al*, *Macromolecules*, 1993, 26, 65.,
- [162] Henderson, J.A., *et al*, *Macromolecules*, 1993, 44, 184.,